Technical Report Documentation Page

1. REPORT No.
CA-HY-MR-5270-1-73-13

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Evaluation Of Bridge Approach Roughness

5. REPORT DATE
June 1973

6. PERFORMING ORGANIZATION
19503-655270

7. AUTHOR(S)
Neal, B.F.

8. PERFORMING ORGANIZATION REPORT No.
CA-HY-MR-5270-1-73-13

9. PERFORMING ORGANIZATION NAME AND ADDRESS
California Division of Highways
Materials and Research Department
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
D-1-6

12. SPONSORING AGENCY NAME AND ADDRESS
California Division of Highways
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
"Evaluation of Bridge Approaches" conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
An objective method of measuring bridge approach roughness and establishing priorities for repair is described. Car body reaction to roughness is recorded on a graph and rating can be established by measuring the vertical movements of the recording pen. The equipment is mounted in a sedan, and an operational speed of 50 MPH over approaches allows for safe, fast recordings under traffic conditions.

17. KEYWORDS
Bridge Approaches, Computer Program Graphs, Maintenance, Rating, Recorders, Repairing, Roughness

18. No. OF PAGES:
28

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1973/73-13.pdf

20. FILE NAME
73-13.pdf

HIGHWAY RESEARCH REPORT

EVALUATION OF BRIDGE APPROACH ROUGHNESS

73-13

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

CA-HY-MR-5270-1-73-13

73-13

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration June, 1973

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE EVALUATION OF BRIDGE APPROACH ROUGHNESS		5. REPORT DATE June 1973 6. PERFORMING ORGANIZATION CODE 19503-655270
7. AUTHOR(S) Neal, B. F.		8. PERFORMING ORGANIZATION REPORT NO. CA-HY-MR-5270-1-73-13
9. PERFORMING ORGANIZATION NAME AND ADDRESS California Division of Highways Materials and Research Department Sacramento, California 95819		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. D-1-6
12. SPONSORING AGENCY NAME AND ADDRESS California Division of Highways Sacramento, California 95807		13. TYPE OF REPORT & PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

"Evaluation of Bridge Approaches" conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

An objective method of measuring bridge approach roughness and establishing priorities for repair is described. Car body reaction to roughness is recorded on a graph and ratings can be established by measuring the vertical movements of the recording pen. The equipment is mounted in a sedan, and an operational speed of 50 MPH over approaches allows for safe, fast recordings under traffic conditions.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Bridge Approaches, Computer Program Graphs, Maintenance, Rating, Recorders, Repairing, Roughness	Unlimited

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	28	

HMRT – 1242 (ORIG. 9/72)

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

June, 1973

M&R No. 655270
Fed. No. D-1-6

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted for your consideration is a report on:

EVALUATION OF BRIDGE APPROACH ROUGHNESS

Study made by	Concrete Section
Co-Investigators	D. E. Currier
	B. F. Neal
Report prepared by	B. F. Neal

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

BFN:fp

Attachment

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The contents of this report reflect the views of the Materials and Research Department which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This project was performed in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Agreement No. D-1-6.

INTRODUCTION

At many bridges in California, the PCC pavement slabs adjacent to the bridge ends have become depressed or otherwise distorted creating a rough ride and, in some cases, safety hazards. Corrections are made by either mud-jacking the slabs back to grade or placing a tapered layer of asphaltic concrete to smooth the approach. The time an approach reaches a condition needing correction and priorities in scheduling this action have long been based on subjective evaluation with much differing of opinions. Since there is never enough time or funds to correct all deficiencies, there is a need for an objective method of evaluating and rating approaches so that priorities can be established. This is especially true in metropolitan areas where there are numerous bridges and the heavy daytime traffic volumes often necessitate nighttime repair work.

For several years, individual maintenance superintendents have experimented with various means of rating approaches. Probably the most promising method was the use of an accelerometer type device which provided a printed record of forces exerted on the instrument when resting on the floor of a car while the car was driven over an approach. One of the drawbacks to its use was that the magnitude of the deviations that could be measured with the instrument being used (measured in G's) was so small that it was difficult to evaluate.

The development of the Road Meter by Max Brokaw of the Portland Cement Association provides a device to measure deviations between the body of a car and its rear axle housing. It was decided that a graph of the car movements should provide an adequate measure of approach roughness. A pooling of ideas with a local manufacturer* resulted in the development of a strip-chart recorder (see Figure 7)

---

*Cox & Sons, P. O. Box 67, Colfax, California 95713, Telephone 916 - 346-8322 to work in conjunction with the Road Meter and provide a graph of the deviations. A mechanical hookup using a cable and pulleys results in a true vertical scale of the body movement relative to the rear axle housing. The chart speed is controlled by the speedometer through potentiometers and is adjustable to provide various scales. A horizontal scale of 1 inch = 25 feet has been established as satisfactory for most uses.

An examination of graphs made of bridge approaches indicated that the Road Meter recorder should be satisfactory in measuring varying degrees of roughness (see Figures 1, 2, and 3). The magnitude of the vertical excursion was considered the most important factor in determining roughness, but the slope of the excursion was also felt to need consideration. These factors are affected by both the speed of the car and the speed of the chart drive. The objective of the study reported here was to evaluate the factors affecting roughness as shown on the graphs and to develop a procedure for rating roughness of bridge approaches.

CONCLUSIONS

1. A strip-chart recorder that provides a graph of deviations between a car body and the rear axle housing is a satisfactory tool for determining priorities for repair of rough bridge approaches. Using the described procedure, ratings can be established for all approaches.

2. A computer program is advantageous in sorting and reducing data to a manageable and more useful form.

IMPLEMENTATION

The Maintenance Department has equipped a car with a strip-chart recorder for use in determining priorities of bridge approach repair. All PCC approaches to bridges in Central and Northern California have been evaluated with the recorder and many of the rougher approaches have been repaired.

DEVELOPMENT OF RATING PROCEDURE

The Road Meter and strip-chart recorder were installed in a 1969 Ford Fairlane sedan, and operational procedures established.

Initially, a car speed of 50 MPH was selected because it is attainable on practically all bridges with PCC pavement approaches. A number of runs were made on several approaches at speeds varying from 20 to 70 MPH to determine whether the graphs made at other speeds would be more satisfactory than those made at 50 MPH. It was found that, for a given roughness, a relationship between various speeds existed but was not linear. In addition, the relationship was not the same on approaches of different roughness, evidently due to effects of the suspension system. It was concluded that a speed of 50 MPH was the most satisfactory and should be used exclusively in the study.

A chart speed providing a scale of 1 inch = 25 feet was established originally to compare directly with the California profilograph records which are made to the same scale. Some experimentation was made with different chart speeds and indicated (1) increasing the scale provided no improvement in the graph but excessive use of paper, and (2) decreasing the scale adversely affected determining the steepness of the excursion. Considering that a steep line would likely be a factor in evaluating the graphs, the chart speed as initially established was maintained throughout the study.

Using the established car and chart speeds, recordings were made of all lanes of all bridges with concrete pavement approaches in Central and Northern California. This resulted in some 6000 approaches to evaluate. Except for the longer structures of about 1000 feet or more, graphs were obtained of the entire bridge as well as some 50 feet of approach on each end. Since there was no event marker or indexing device on the recorder to identify bridge notches on the graphs, it was difficult in some cases to determine the exact area of concern. As best as could be determined, however, the bridge ends were marked on the graph and the maximum excursion of the pen was measured. This was accomplished by placing a plastic template over the trace and counting the scribed lines (in 1/8-inch increments) covering the excursion. The number of lines thus counted was then recorded initially as the approach rating.

A subjective evaluation then became necessary to determine the meaning and accuracy of the ratings. This was done first by the researchers riding over and observing approaches and making judgments as to the degree of roughness and comparing this to measured ratings. In most cases, roughness was attributable to settled or depressed pavement slabs, and usually within 25 or 30 feet of the paving notch. Occasionally, the pavement slabs were observed to be higher than the paving notch at that point.

It was concluded that the steep lines occurring on some graphs were due to differential vertical displacement of approach slabs or of the paving notch and approach slab. When the car wheels hit a vertical displacement, the result was an abrupt movement of the car body and a steep pen excursion (step) on the chart. Because of the severity of car reaction to these steps and the possibility of affecting vehicle control, it was decided that some additive value to the measured roughness rating was needed. On a tentative basis, arbitrary values of 4 for a step up, and 2 for a step down were selected. The higher value was based on subjective opinion that a vertical step up could be seen by a driver, who might immediately fear tire damage, and was therefore more potentially serious than a step down. A line 8° or less from the vertical is considered a step. (See Figure 4.)

Using the established method, ratings were calculated for bridge approaches in the Sacramento area. These ratings ranged in value from 3 to 22. To relate these values to descriptive roughness, a panel of nine raters was selected to make subjective evaluations of some 40 bridge approaches of varying degrees of roughness. Raters included bridge and research engineers, and laboratory technicians. After receiving instructions and making trial runs over other approaches, raters were taken over the selected approaches and asked to apply ratings according to the following:

Description	Subjective Rating
Smooth ----------------	1
Slightly rough ---------	2
Rough -----------------	3
Very rough ------------	4

Unfortunately, for the purposes of this study, four of the roughest approaches selected had been repaired before evaluation by the raters. Of the 36 approaches remaining, the highest measured rating was 17. Following is a summary of the raters' evaluations and a comparison with the measured ratings:

Description	Weighted Average of Subjective Rating, Range	Range of Measured Rating	No. of Approaches
Smooth	1-1.5	3-7	7
Slightly rough	1.6-2.5	6-12	25
Rough	2.6-3.2	14-17	4
Very rough	Over 3.2	-----	0

From these findings, tentative rating criteria were established:

1. Approaches with measured ratings of 12 or less are considered acceptably smooth and generally do not need any corrective action.

2. Approaches with ratings of 16 or greater, need repair, and those with highest ratings should be given priority.

3. Those with ratings between 12 and 16 are in a gray area and should be checked periodically. While some may need correction, they should be given lower priority than approaches rated 16 or more.

Using the above criteria, all approaches in the Central and Northern California area were rated and a tabulation made of the results. A computer program was then written to provide better order to the information. Since much of the data were already outdated, the primary consideration was to show how the information could be depicted in printed form and used by maintenance forces. While items such as bridge name, county, etc. might be desirable on a working printout, headings were held to a minimum to conserve time and expense.

Figure 5 is an example of the computer printout. Although there are various ways the data could be presented, it was decided to break it down by highway routes. Bridge numbers are then listed in order of their post mile designations. The direction of travel and lane number is listed; e.g., E4, eastbound number 4 lane. Measured ratings for both ends of the bridge and any additive value for steps are given next, and finally, the Average Daily Traffic figure for the highway section involved. The ADT can be of value in determining priorities when several approaches have approximately equal needs for repair.

Approximately 3000 lines were required to print all of the data from the Northern and Central California bridges. To reduce this to a more workable level, the computer was programmed to print only those bridges with at least one approach having a rating greater than 12. The resulting printout had only 589 lines, a reduction of about 80%. (See example in Figure 6.) There were 656 approaches with ratings greater than 12, and of these, 358 were less than 16. The 298 with ratings 16 or over were broken down as follows:

Rating	No. of Approaches	Rating	No. of Approaches
16	112	24	7
17	35	25	3
18	70	26	2
19	20	27	0
20	30	28	1
21	4	29	1
22	7	30	0
23	5	31	1

To check on changes in roughness after about 18 months, reruns were made on several of the bridges with at least one rough approach. Following are sample results of these reruns:

	Approach		Leave	
Bridge	1971	1972	1971	1972
29-140L	14	13	16	16
38-96L	5	3	14	13
38-78L	8	7	14	15
46-35L	20	3 *	9	8
46-151L	8	11	15	16
46-56R	11	9	16	3 *
46-36R	9	14	18	11 *
39-133R	3	4	13	15
39-137R	4	3	15	19

Continued

Bridge	Approach 1971	Approach 1972	Leave 1971	Leave 1972
38-72R	16	15	3	4
38-78R	3	6	13	13
24-21R	3	4	20	4 *

*AC patch

Some variations in results can be expected due to wheeltrack deviation, spring and shock absorber reaction, or differing measurement techniques. Out of 56 approaches checked, only five had increased in roughness by three points or more. Four of the roughest approaches had been patched, three rather effectively.

As previously mentioned, many of the rougher approaches were repaired between the 1971 runs and the rerun checks in 1972. Selection of areas for repair were made subjectively by the maintenance crews. On one highway section, it was found that 22 approaches (usually all lanes) had been repaired since the 1971 runs. Of these, 18 had original ratings of 16 or more, 2 rated 14, 1 rated 9, and 1 rated 8. The rating at time of repair is not known though it appears safe to assume they were near the original level. The results of this appraisal lend further support to the arbitrarily selected value of 16 as nearing the maximum roughness to be tolerated safely.

A re-evaluation of the rating procedure indicated two weak points which could lead to errors. One of these was the lack of an event marker to indicate exact locations of bridge notches. Such a device had been considered during construction of the recorder but due to space limitations, had been left off. Without previous experience, it was feared that very rough approaches would result in movement of the recording pen carriage to the extremes of travel, and restrictions to the amount of travel would cause the cable to break. Experience with the equipment has shown that maximum excursions of the carriage are rare, and having an event marker was deemed worth the risk of a cable breaking. With some modification of the pen lifting mechanism, a second pen holder was added at one side of the recorder so that the pen would mark along the bottom edge of the chart. (See Figure 8.) The charts of approaches and bridges now provide much clearer information than previously available.

(Compare Figures 9 and 10 with 11 and 12.)

A second weak point was the additive factor for steps up and down. While originally it was thought to be most likely that there would be a step up on the approach side and a step down on the leave side, this was not proven to be the case. In addition, some approaches indicate steps both up and down, due to reactions of car springs and shock absorbers (see Figure 13). This further evaluation, both of the charts and in the field, has led to changing the additive factor to 4 for steps in either direction.

SUMMARY

The strip-chart recorder attached to a PCA type Road Meter is believed to be a satisfactory device for determining relative roughness of bridge approaches. A car speed of 50 MPH and a chart speed providing a horizontal scale of 1 inch = 25 feet has been shown to provide best results. By measuring the maximum vertical excursion of the pen on the chart (over the approach area) in 1/8-inch increments, a roughness rating is established. A steep excursion, either upward or downward, indicates a shock to car and driver, and requires an additive value of 4 to the measured rating. The addition of an event marker greatly simplifies interpretation of the recordings.

From the ratings of approaches under consideration for repair, priorities can be established. Although some engineering judgment must be exercised, such as taking into account the amount and speed of traffic using the roadway, generally the approaches with highest ratings should be repaired first. Approaches with ratings of 16 or greater are considered to need repair as soon as possible. Those with ratings between 12 and 16 are borderline and should be watched closely and repaired as time and money permit.

A computer program is helpful in sorting and presenting the data. When a large number of ratings is involved, a selective retrieval system is advantageous in reducing the volume of data while still printing the desired information.

The established procedure was developed in conjunction with subjective opinions of a panel of engineers and technicians. The tentative criteria for repair are ratings of 16 or greater. This is further supported by the number of bridge approaches meeting or exceeding this criteria that were repaired during the year following the original rating. Obviously, this system is not needed in all areas of the state, but where there are a great number of bridge approaches needing repair, with time and money limitations, the procedure described here can be used to great advantage in setting priorities.

GENERAL OPERATING INSTRUCTIONS

1. Plan route to be followed. Since all runs must be identified, it is desirable to have bridges listed in order before starting runs.

2. Load chart paper into recorder.

3. Energize pen lifts and chart drive and push advance button to assure that all systems are working.

4. Adjust profile pen to center of chart when driver and operator are in position in front seat of car.

5. With car moving at 50 MPH, turn pen and chart switches on about 50 to 75 feet in advance of bridge notch. Depress event marker switch when front wheels of car cross bridge notch on the approach side and again when the front wheels cross the notch leaving the bridge. Leave chart running and pen down for another 50 to 75 feet, then raise pen, but allow chart to run a few inches before turning off.

6. Number the run next to the bridge identification. Lane number and direction of travel should also be noted.

NOTES

In lieu of listing all bridges, a tape recorder can be used to identify location, lane, direction, etc.

A roll of chart paper may hold runs of 40 or more bridges. It is very important that referencing be accurate. To aid in this, rolls can be numbered, the first bridge can be referenced on the chart before starting. When stopped for any reason, the previous run can be referenced on the chart, and the foot number showing on the chart can be referenced to an occasional run. To avoid errors, it is also advisable to label both ends of a roll with some type of identification.

Check calibration of longitudinal scale occasionally by running over a known distance of 1000 feet or more. (Be sure to make runs at 50 MPH.) If scale is off by more than 2%, adjust the large potentiometer until scale is within limits.

Check adjustment of pen pressure on the chart at frequent intervals. Too much pressure may cause tearing of the paper and too little will result in a faint trace which is difficult to analyze.

EVALUATION OF CHARTS

1. Select the portion of approach and end of deck showing greatest pen excursion. Place template (divided into 1/8-inch increments) over lines and measure between the extreme top and bottom limits. Record the number of 1/8-inch units as the measured rating.

2. On graphs showing steep vertical excursions (between 82° and 90° on a protractor), mark the approach as having a step and add 4 points to the measured rating. This constitutes the overall roughness rating.

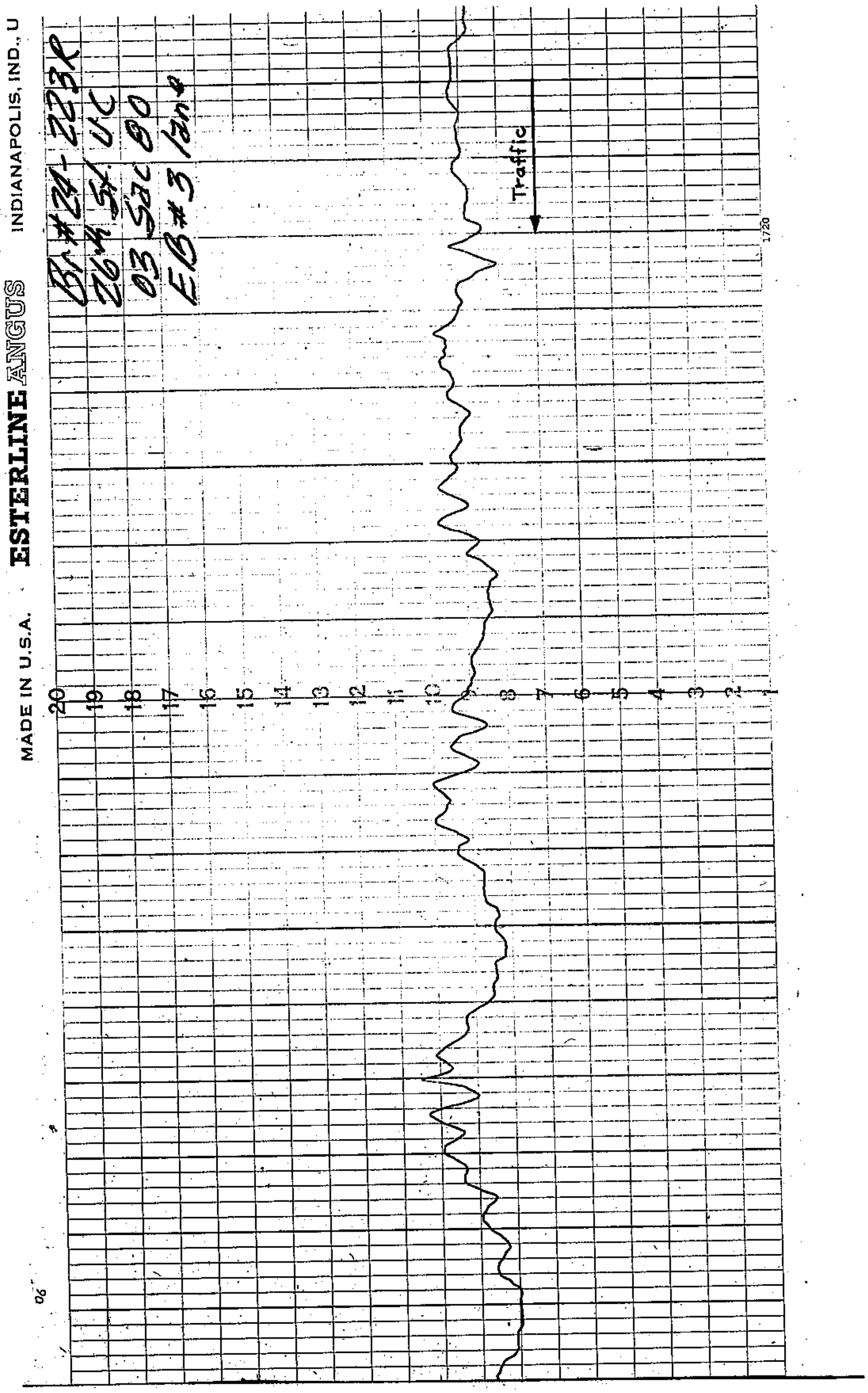

Figure 1
Smooth to Slightly Rough Approaches

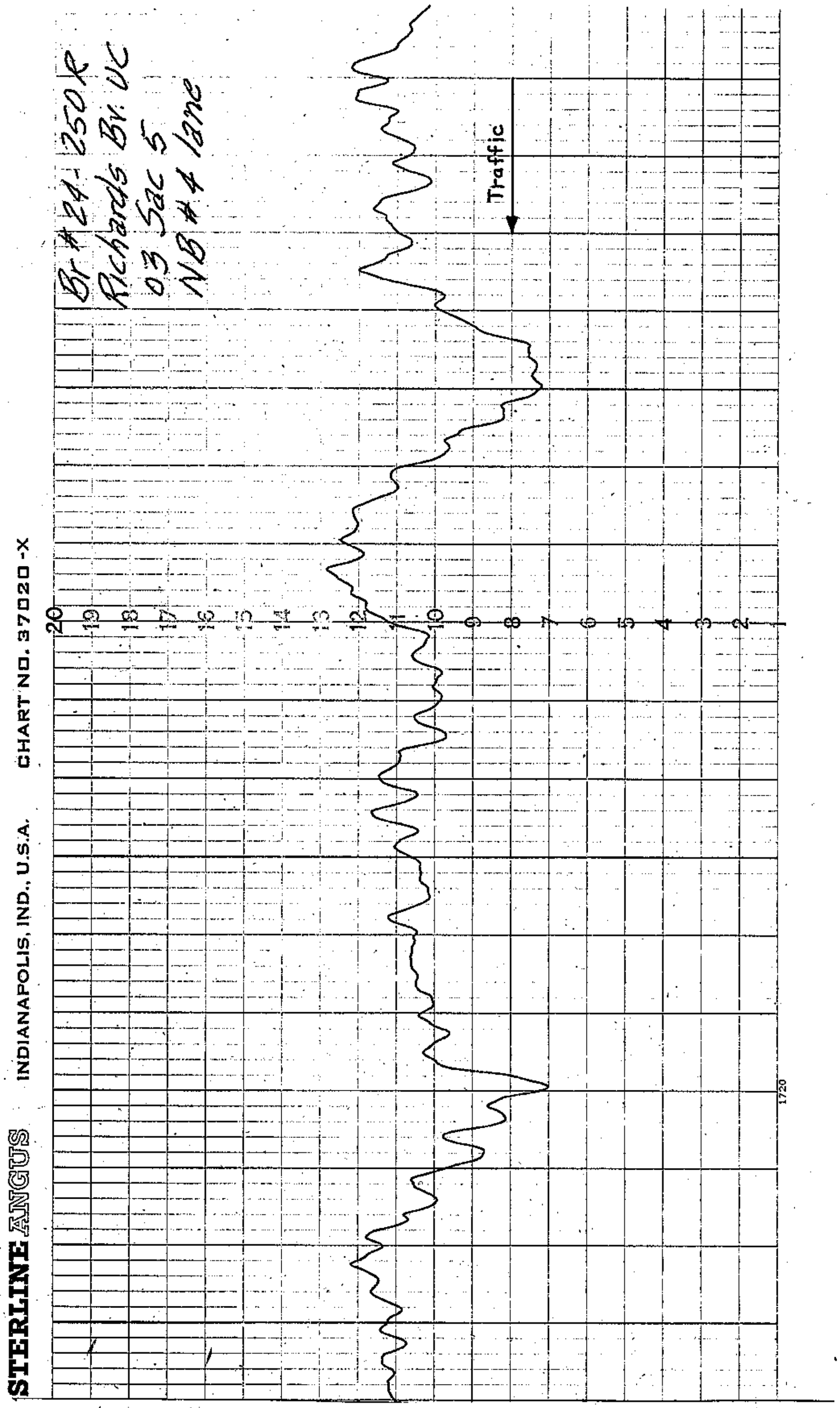

Figure 2
Medium Rough Approaches

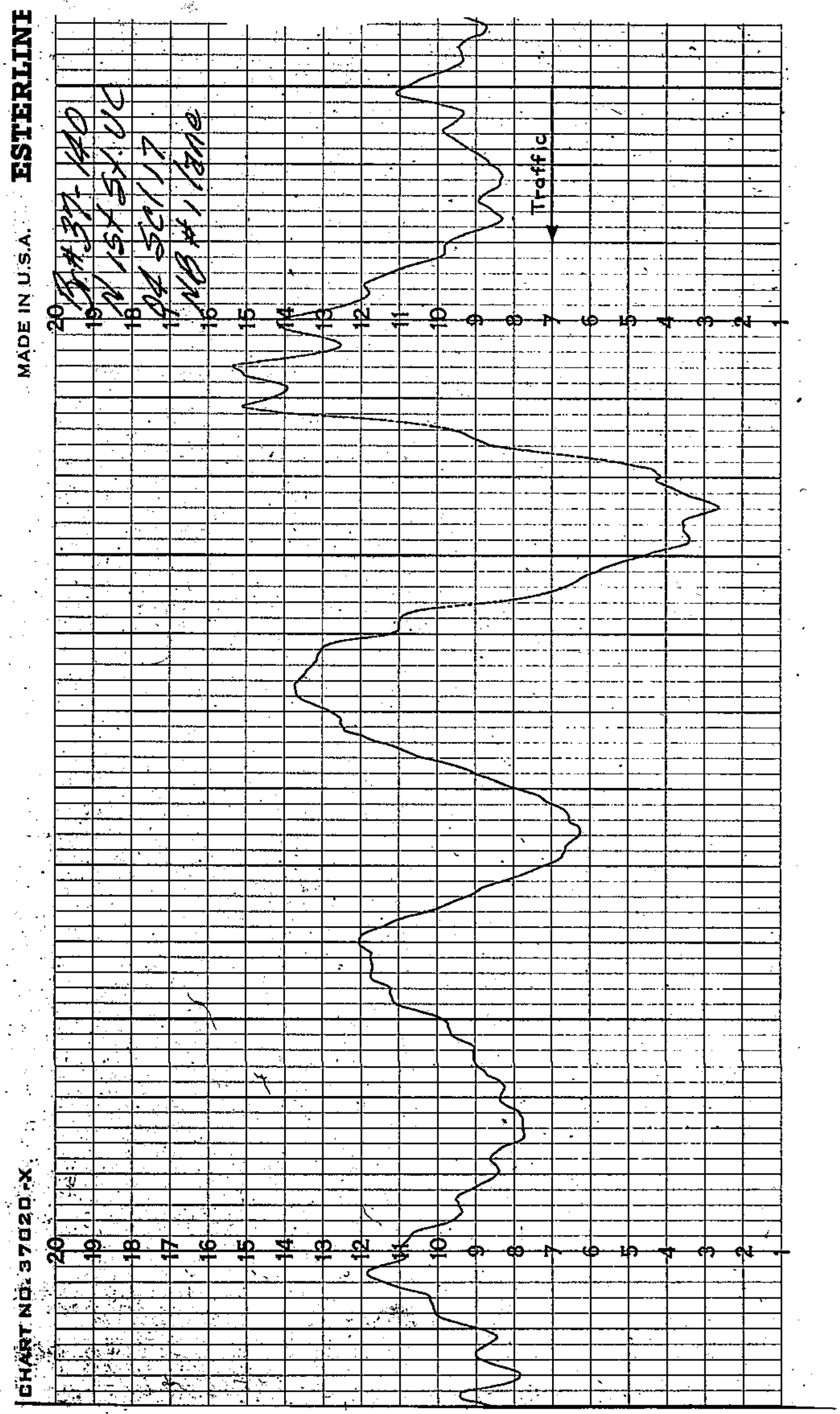

Figure 3
Very Rough Approach

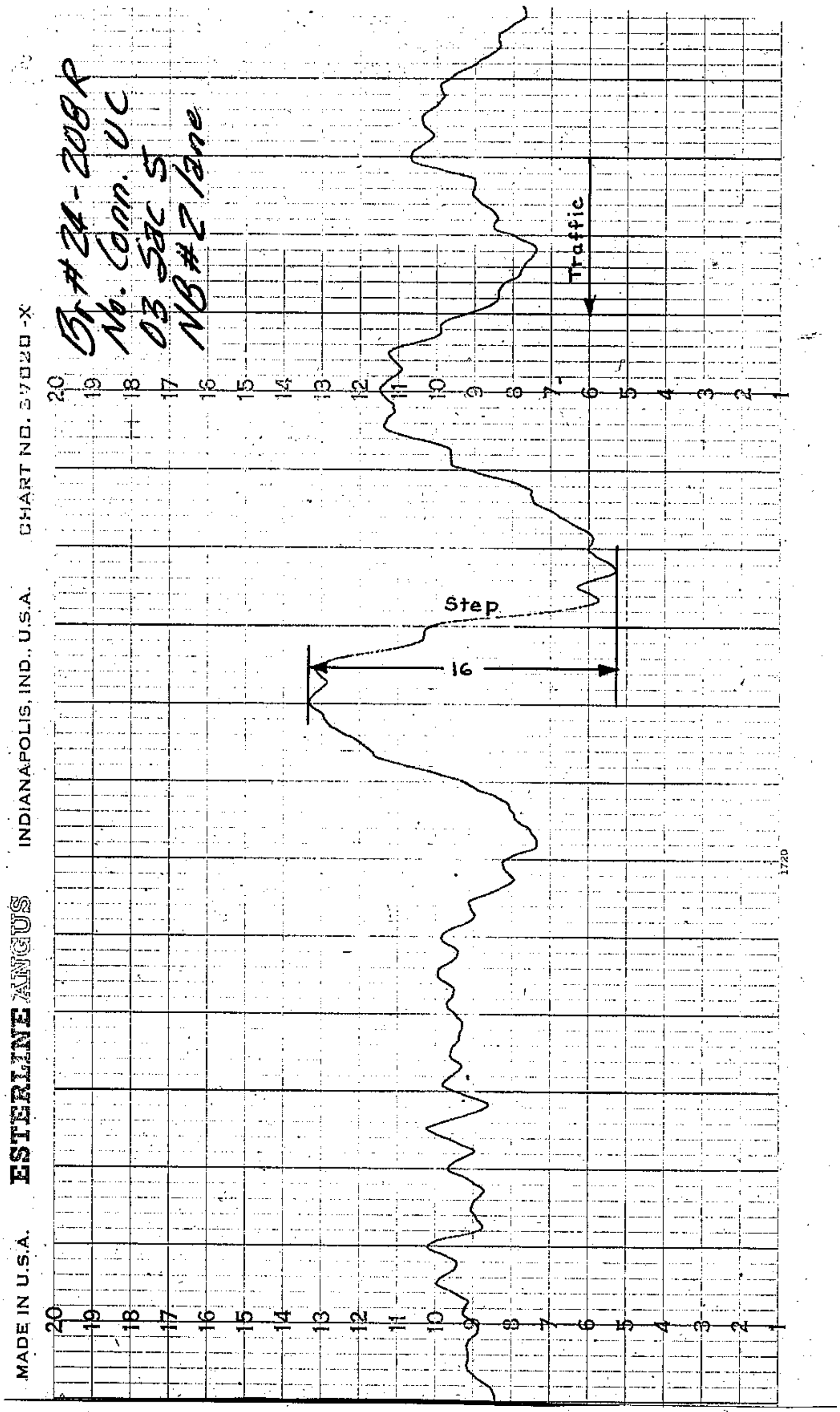

Figure 4
Steep Excursion or "Step"

BRIDGE APPROACH DATA
HIGHWAY RT 580
MARCH 71

BRIDGE NUMBER	POST MILE	LANE	APPROACH AMPL.	APPROACH STEP	APPROACH RATING	LEAVE AMPL.	LEAVE STEP	RATING	ADT
33-395R	31.71	N3	5	0	5	15	2	17	76000
33-395R	31.71	N4	6	0	6	13	2	15	76000
33-395L	31.71	S1	5	0	5	13	0	13	76000
33-395L	31.71	S2	6	0	6	10	0	10	76000
33-395L	31.71	S3	5	2	7	4	0	4	76000
33-395L	31.71	S4	8	0	8	15	0	15	76000
33- 331	34.40	N1	6	0	6	3	0	3	84000
33- 331	34.40	N2	4	0	4	6	0	6	84000
33- 331	34.40	N3	3	0	3	3	0	3	84000
33- 331	34.40	N4	6	0	6	3	0	3	84000
33- 331	34.40	S1	8	0	8	3	0	3	84000
33- 331	34.40	S2	3	0	3	4	0	4	84000
33- 331	34.40	S3	4	0	4	4	0	4	84000
33- 331	34.40	S4	9	2	11	9	0	9	84000
33- 332	34.48	N1	10	0	10	7	0	7	89000
33- 332	34.48	N2	11	4	15	11	4	15	89000
33- 332	34.48	N3	7	4	11	6	0	6	89000
33- 332	34.48	N4	9	0	9	6	0	6	89000
33- 332	34.48	S1	12	2	14	14	2	16	89000
33- 332	34.48	S2	14	0	14	3	0	3	89000
33- 332	34.48	S4	14	2	16	12	4	16	89000
33- 07	34.55	N1	10	2	12	4	0	4	89000
33- 07	34.55	N2	13	2	15	6	4	10	89000
33- 07	34.55	N3	10	2	12	6	2	8	89000
33- 07	34.55	N4	13	0	13	8	0	8	89000

Figure 5
Sample of Computer Printout

BRIDGE APPROACH DATA
RATING > 12
HIGHWAY RT 80
MARCH 71

BRIDGE NUMBER	POST MILE	LANE	APPROACH AMPL.	APPROACH STEP	APPROACH RATING	LEAVE AMPL.	LEAVE STEP	LEAVE RATING	ADT
24-243R	.66	E1	13	0	13	8	0	8	54000
24-243L	.66	W3	16	0	16	11	0	11	54000
24-243L	.66	W4	14	0	14	0	0	0	54000
24-244R	.89	E4	14	0	14	18	0	18	54000
24-245L	.96	W1	3	0	3	18	2	20	54000
24-245L	.96	W3	6	0	6	9	4	13	54000
24-247R	1.36	E3	14	2	16	7	0	7	68000
24-247R	1.36	E4	12	2	14	9	0	9	68000
24-188R	3.06	E4	12	2	14	AC	-	-	94000
24-188L	3.06	W2	12	2	14	8	0	8	94000
24-190R	3.76	E4	9	4	13	3	0	3	90000
24-192R	3.92	E4	10	4	14	4	0	4	102000
24- 03	5.19	E3	18	2	20	AC	-	-	102000
24- 03	5.19	W3	13	2	15	7	2	9	102000
24- 133	5.71	E3	10	2	12	12	4	16	102000
24-130R	6.21	E2	10	2	12	17	2	19	79000
24-130L	6.21	W3	14	4	18	22	0	22	79000
24-115L	6.62	W2	6	2	8	12	2	14	100000
24-132R	6.71	E2	14	0	14	14	2	16	100000

Figure 6
Computer Printout
Rating > 12

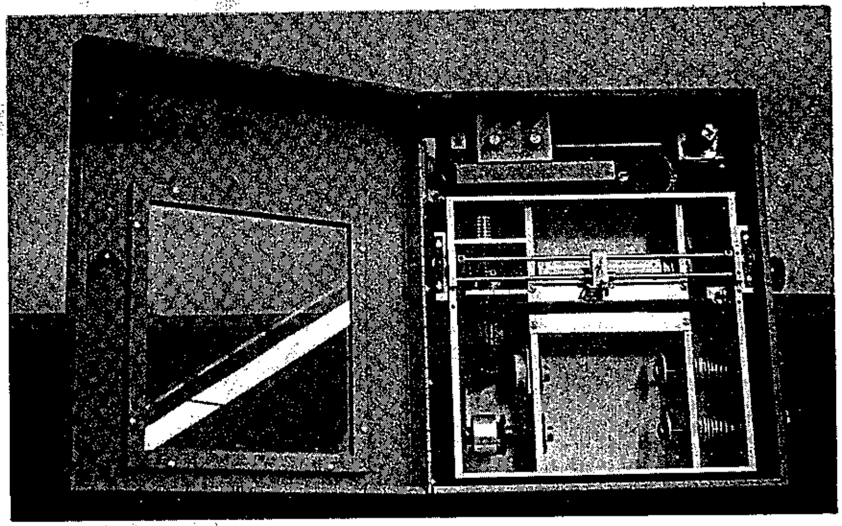

Figure 7
Original Recorder

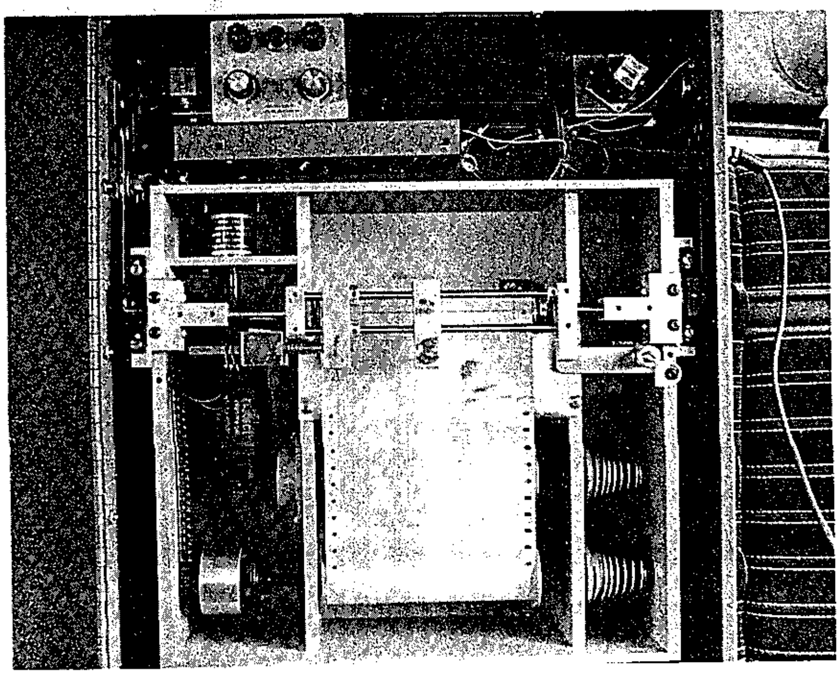

Figure 8
Recorder with Event Marker Added

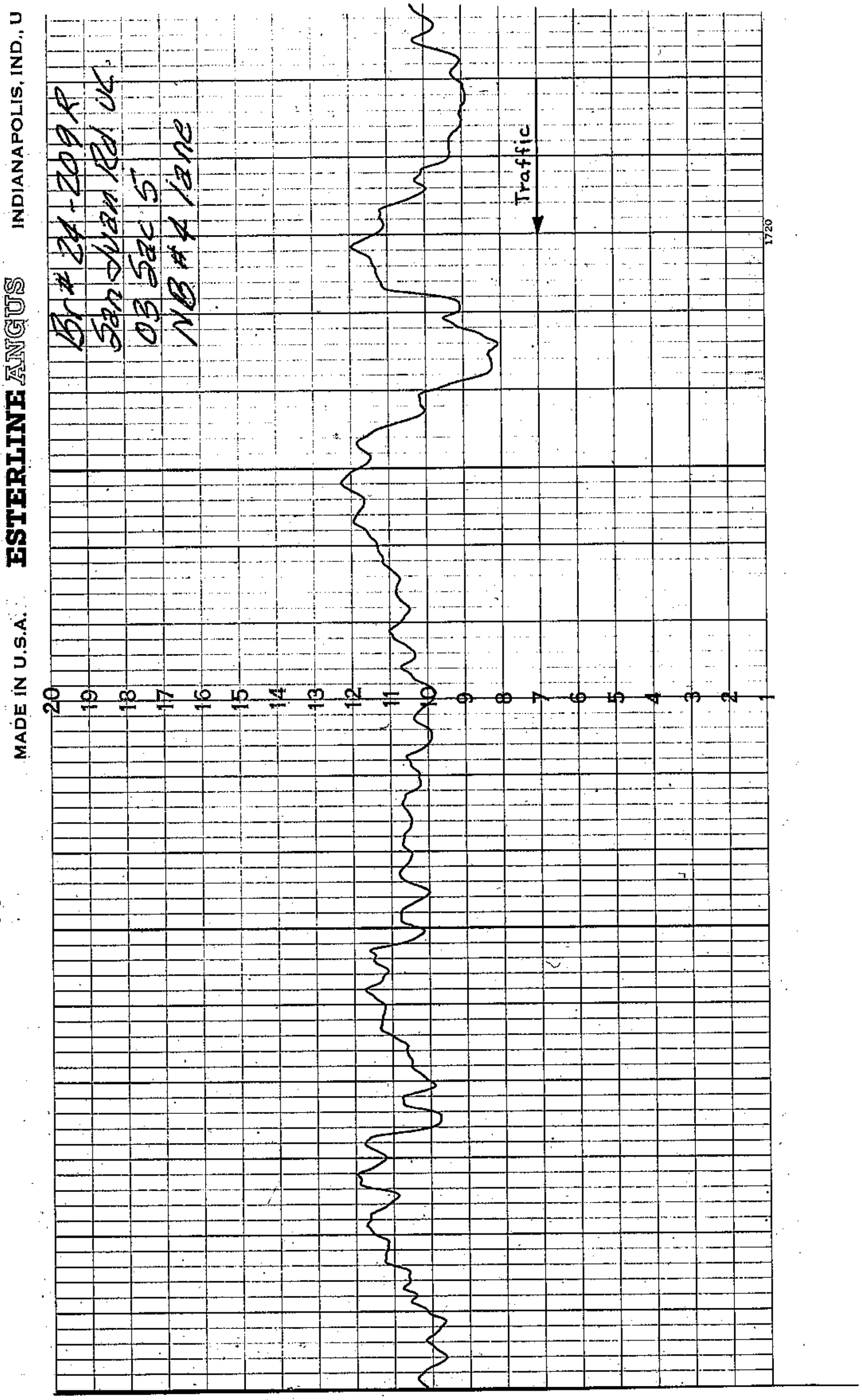

Figure 9
Graph without Event Marker

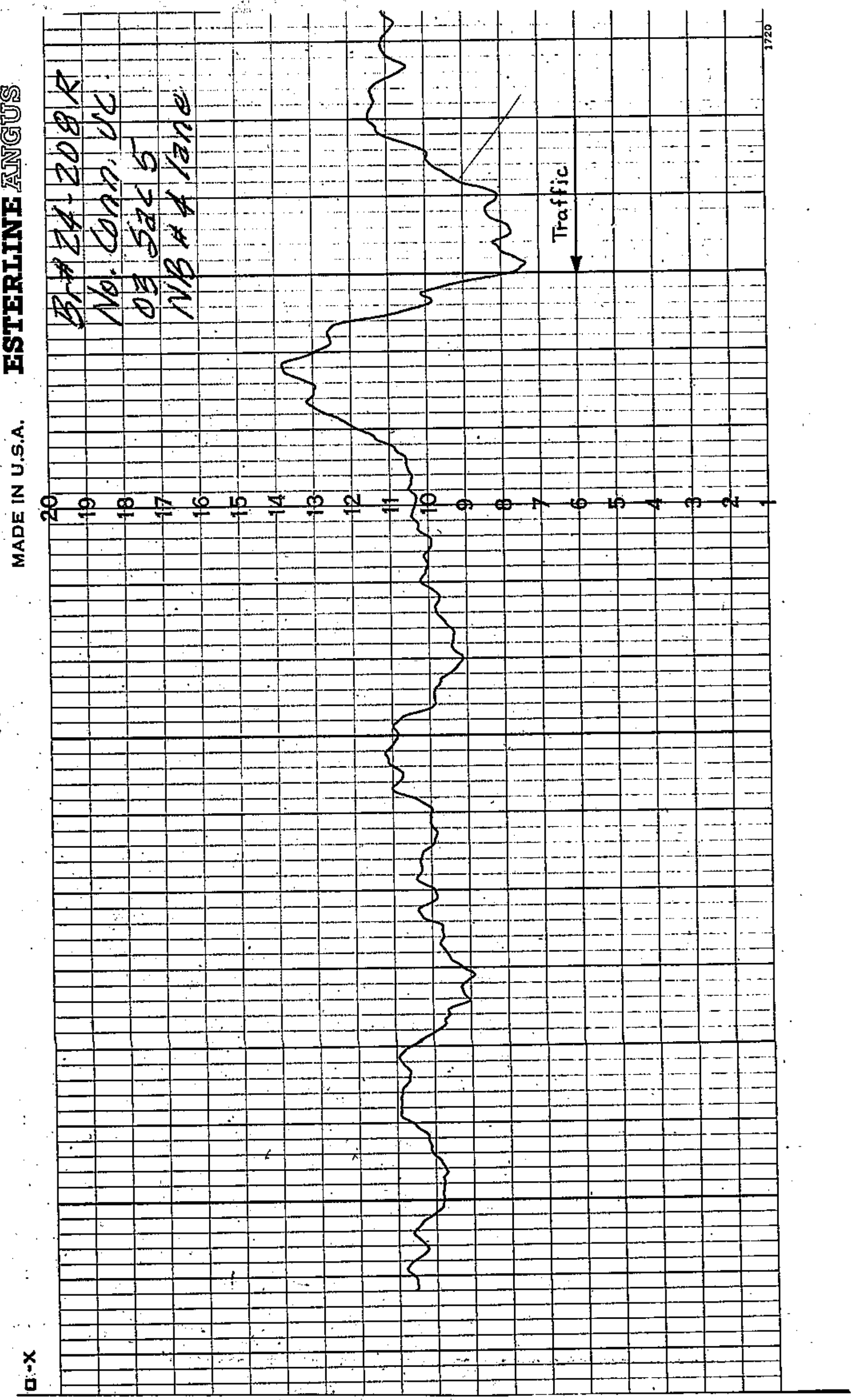

Figure 10
Graph without Event Marker

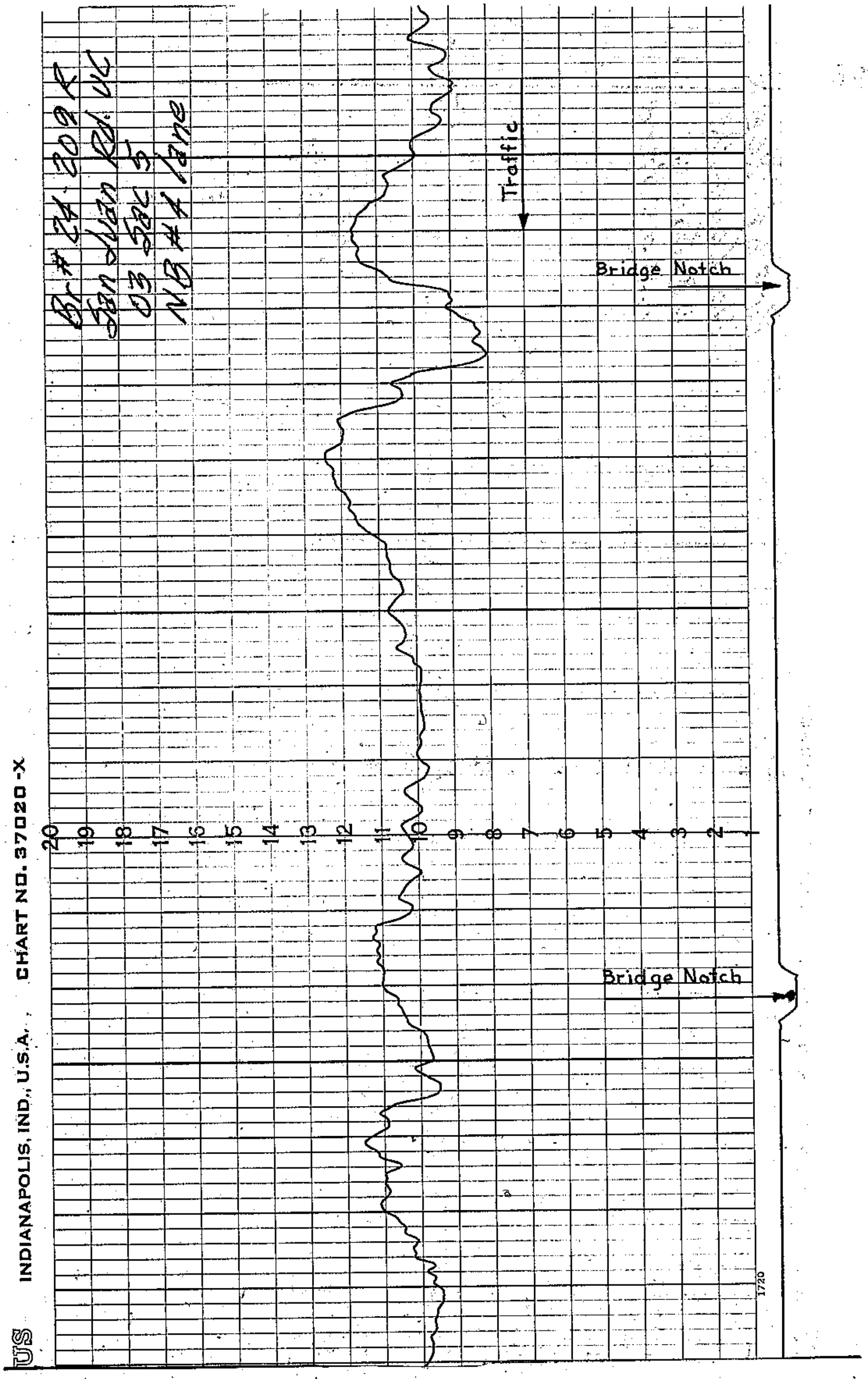

Figure 11
Same as Figure 9 but with Bridge Notches Marked

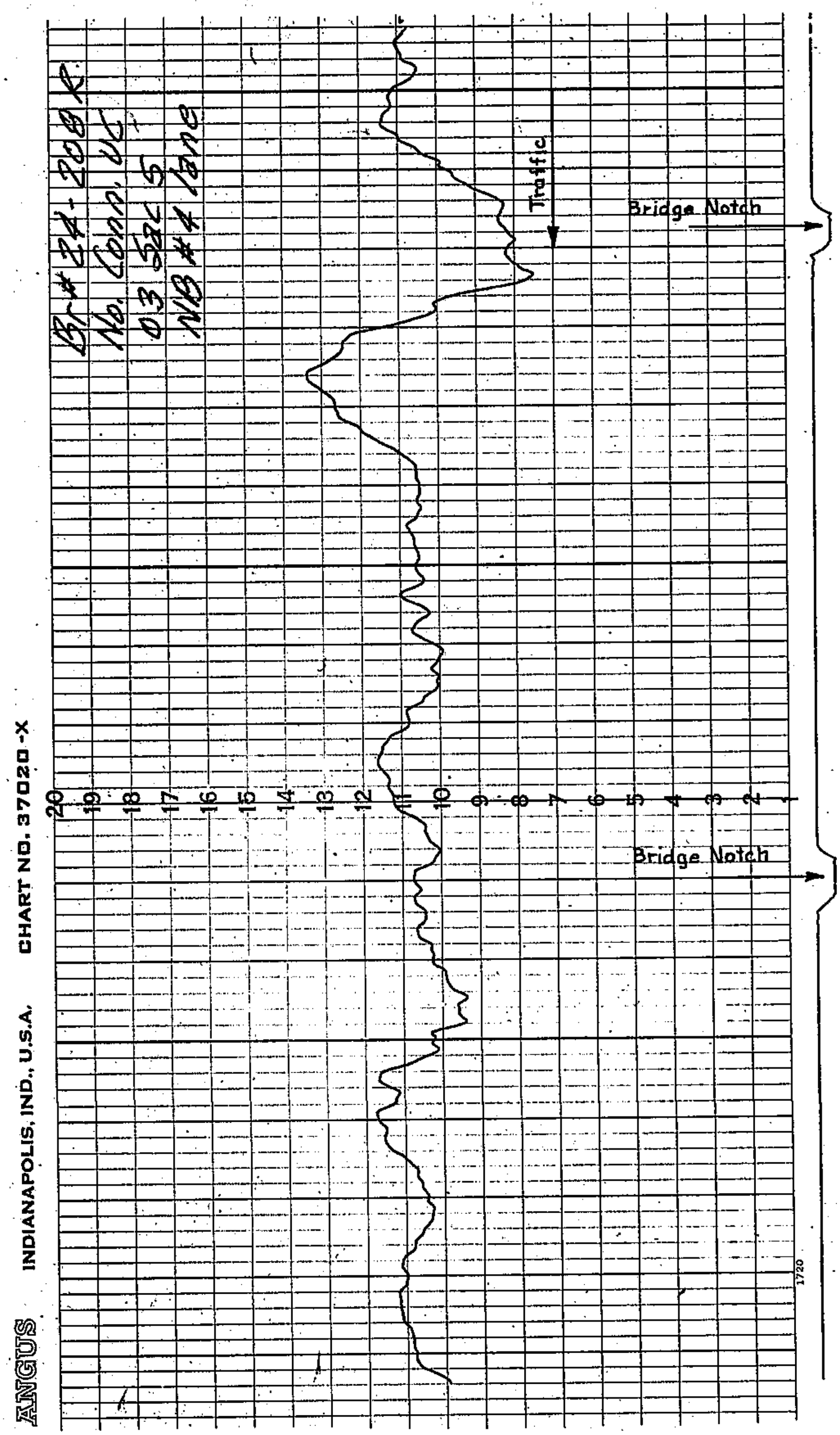

Figure 12
Same as Figure 10 but with Bridge Notches Marked

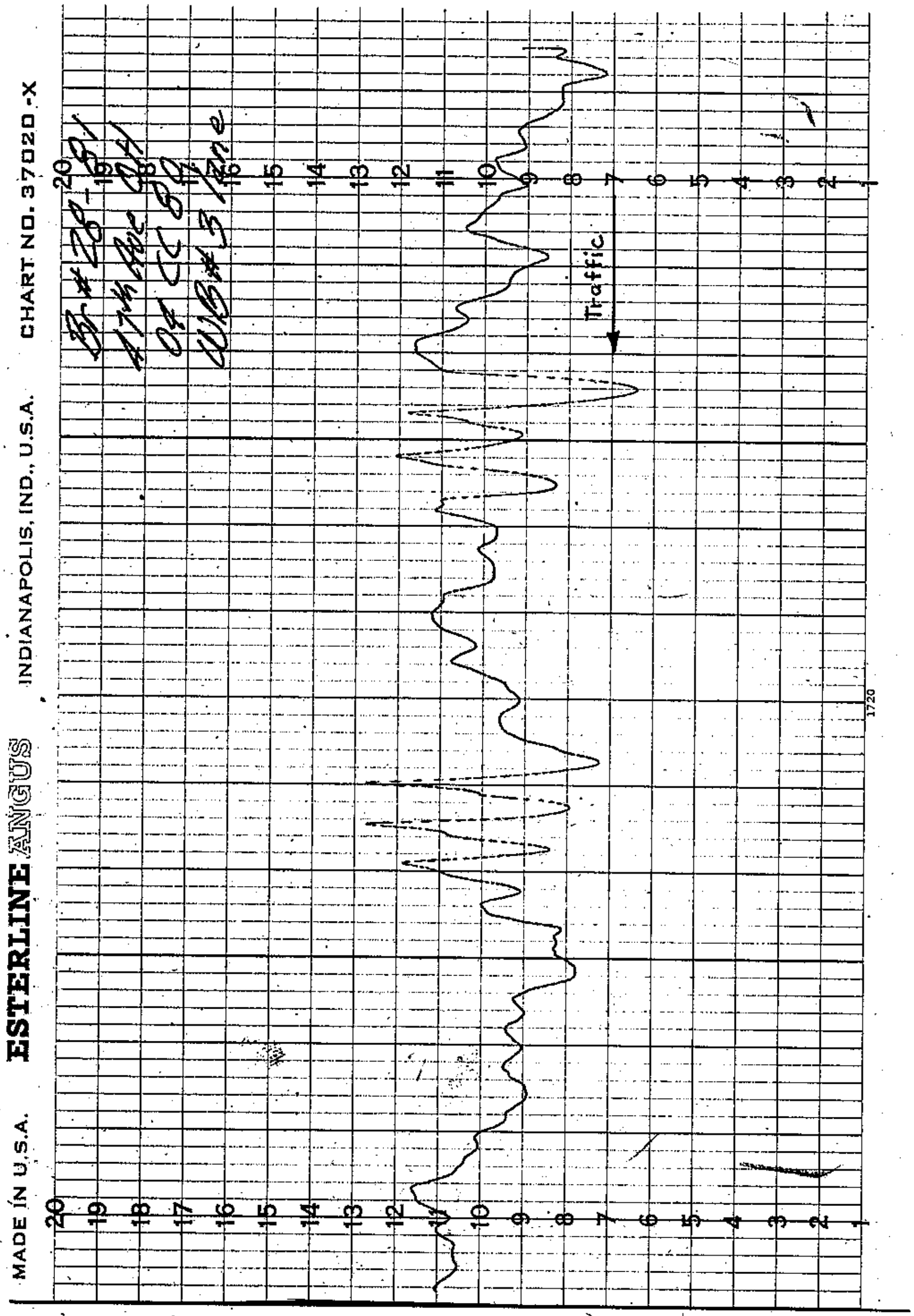

Figure 13
"Steps" Both Up and Down

ADDENDUM

The purpose of this addendum is to clarify specific questions raised since completion of the final draft.

Equipment

The recorder was originally built to serve as a prototype but has undergone only minor changes since construction. There have been no significant maintenance problems and only an occasional necessary adjustment to the clutch of the paper take-up roller. The unit can be built and installed for less than $1500. A Road Meter is not necessary to the operation of the recorder.

Operation

The equipment is not difficult to operate but does require considerable coordination. The timing of activating switches to control chart drive, pen drop and indexing is very critical at a car speed of 50 mph. It was found preferable that the driver, rather than the operator do the indexing, with a remote control switch. Very little training is needed for an operator but a few hours of practice operation is desirable before starting. Obviously, the number of runs that can be made in one day is highly variable. During the survey discussed in the report, it is estimated that on the average, about 100 bridge lanes (200 approaches) per day were run. For each day in the field, about eight man hours of office work is required to complete the referencing, indexing, and rating. The man hour cost is thus about one man hour per eight approaches, plus car and other expenses.

Repeatability

Repeatability of results has been considered excellent, with practically all reruns having ratings within 2/8-inch of the original. Most work has been done with the equipment mounted in a 1969 Ford Fairlane. Later it was placed in a 1972 American Motors Matador. Results checked very closely with those from the Ford as long as shock absorbers and wheel alignment and balancing were maintained closely. Recently the Road Meter and recorder were transferred to a 1973 Plymouth station wagon. A correlation check of the recorder in this vehicle has not been completed. It appears that results will be slightly different, with a little less roughness showing on the smoother approaches and somewhat greater on the rougher approaches. This is not considered to be a problem in the continuity of bridge approach roughness measurement program, however.

Table on Page 6

To clarify the term "Weighted Average of Subjective Rating" of Table 6, the following examples are given for two different bridge approaches.

Example 1

Subject Rating	No. Ratings Received*	Calculation
1 (Smooth)	2	2 x 1 = 2
2 (Slightly Rough)	6	6 x 2 = 12
3 (Rough)	1	1 x 3 = 3
4 (Very Rough)	0	0 x 4 = 0
Total	9 people	17

Weighted Avg. = 1.9 (17 ÷ 9)

*Of 9 individuals, ratings were dispersed as shown.

This rating falls in the "Slightly Rough" category.

Example 2

Subject Rating	No. Ratings Received	Calculation
1	0	0 x 1 = 0
2	0	0 x 2 = 0
3	7	7 x 3 = 21
4	2	2 x 4 = 8
Total	9 people	29

Weighted Avg. = 3.2

This rating falls in the "Rough" category.